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APOLLO PROGRAM

LM LANDING POINT DESIGNATOR PROCEDURES AND CAPABILITY

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SUMMARY

The capabilities and procedures associated with the PGNCS Landing Point Designator are discussed and a final approach redesignation logic is formulated in order that a desirable landing area may be achieved by the LM. Specific procedures are outlined, and an example case of the LM's capability is discussed.

INTRODUCTION

The objective of this report is to explain the procedural logic of utilizing the Lunar Module's Landing Point Designator (LPD) capability within the Primary Guidance, Navigation, and Control System (PGNCS) during the final approach to the lunar surface. The capabilities and constraints involved in successfully utilizing the LPD were established as the result of studies and simulation and are summarized herein to aid in defining the operational redesignation logic.

DISCUSSION

A simple definition of the LPD process is the capability within the PGNCS for the LM Commander to manually augment that system in driving the vehicle to a desirable landing point based on visual information. Reference 1 outlines the concept of this process and the method by which the LM PGNCS modifies the quadratic guidance commands based on crew line-of-sight input data. Figure 1 depicts the LM cockpit configuration and the pertinent system components used by the crew, after higate, for evaluating the final approach progress. The DSKY will display a look angle with respect to the positive "Z" body axis to the LM pilot. A simple reticle which is etched on the inner and outer window surfaces will orient the Commander's field of view to the desired look angle. The LM Pilot calls out the look angle displayed on the DSKY

while the Commander views the intended landing area by orienting his line-of-sight using the reticle. The means of manual redesignation of the landing point is the attitude hand controller. Each motion of the controller out of the detent position sends a discrete angular input to the LGC, either downrange ($\pm\frac{1}{2}^{\circ}$) or crossrange ($\pm 2^{\circ}$) along the Commander's LOS to the computed landing point. Thus, the Commander can observe approximately where the automatic guidance is taking him by noting the intersection of the LPD-LOS with the surface and can redesignate as required.

An analytic study concerned with LM-LPD operational capabilities and constraints was performed to supplement existing manned simulation experience. The mathematical model used in the study considered no error dispersions or other deviations in the LM nominal descent trajectory prior to higate. Five LM altitudes above the lunar surface were chosen for evaluation: 7000, 5000, 3000, 1000, and 500 feet. All redesignation inputs were considered to be instantaneous as were the attitude and thrust level reactions corresponding to a particular, commanded redesignation as governed by the LM quadratic guidance equations. The following quantities were derived from the analytic study: time-to-go to the terminus of the phase, terminal vehicle yaw angle (or final heading; see ref 2), commanded engine thrust, additional characteristic velocity $\Delta(\Delta V)$ required to make good the new landing point (see ref 3), line-of-sight to the new landing point, and pilot oriented roll, yaw, and change in pitch of the vehicle.

Another result presented in this report is LPD operational procedures as derived from manned-hybrid simulation experience. The procedures are designed to compensate for possible system errors induced by LPD reticle misalignment and/or terrain variation (as defined by the Lunar Landing Site selection terrain criteria, see ref 5).

RESULTS

Figure 2 shows the LM fully automatic landing, 3σ dispersion ellipse superimposed on a high resolution Orbiter II uncontrolled mosaic photograph of primary site 6. The 3σ ellipse is oriented with its 26,100 ft major axis along the nominal east-west LM approach ray. The 17,300 ft minor axis defines south to the left and north to the right, as viewed. Figure 3 shows the unconstrained redesignation capability of the LM at 7000 ft altitude superimposed on the landing ellipse. Note the LM's position, some 25,600 ft uprange of the center of the ellipse or nominal landing point. The characteristic velocity (or ΔV) contours shown in figure 3 represent increments in the presently budgeted (90 ft/sec) landing point redesignation allowance. It can be seen that an unconstrained LM has the capability to go any place across the minor axis of the ellipse with reference to the nominal landing point. Likewise,

the landing point could be redesignated some 7,200 ft downrange without exceeding the ΔV budget allowance. Also, if, due to automatic guidance dispersions, the LM's landing point were on the edge of the ellipse, it is conceivable that the command pilot might redesignate to a satisfactory landing area outside of the ellipse. The objective here is...That the Command Pilot will try to get the LM down to any safe landing area.

To further define the redesignation capability of the LM at 7000 feet altitude, several constraints that the Command Pilot would encounter have been superimposed on figure 3 to produce figure 4. The shaded area represents what would be obscured by the frame of the LM window and the forward edge of the external structure as seen from the Commander's "design eye position". Clearly, a large portion of the right half of the footprint will be unavailable because of lack of visual assessment capability by the Commander. Another visibility limitation area will be located directly uprange of the nominal landing point. Under normal conditions nothing should obscure the Commander's line-of-sight (LOS) to this area, but, if he should command the LM Guidance Computer (LGC) to redesignate the landing point into this area, the vehicle would not only have to increase the descent engine throttle setting to get down more quickly but would also have to pitch backward such that the LOS to the target would be lost (i.e., the new landing point would disappear behind the bottom of the window frame as seen from the Commander's design eye position). Redesignating short of the nominal landing point should indeed conserve ΔV but would greatly degrade visibility of the new landing point. Since the LM descent engine is throttleable only up to 60% of maximum power and then jumps to full thrust, it is highly desirable to keep the engine thrust setting in the 10 to 60% throttleable region for operationally reliable guidance. The maximum throttleable engine setting (60%) is plotted on figure 4, and it would only influence very short or very wide redesignations. Lateral or crossrange landing point redesignations cause the LM to bank much like an aircraft. The maneuver is composed mainly of roll and yaw rotations accompanied by a slight pitch forward (toward the vertical). Since there may exist vehicle roll angles, caused by lateral redesignation, that under certain state vector conditions could cause a short duration Landing Radar (LR) data degradation, vehicle roll gradients were plotted to establish the LM's reaction to combinations of crossrange and downrange redesignations. With some of the known LM-LPD constraints superimposed upon the ΔV footprint contours a more realistic assessment of what is the LM's operationally available redesignation capability begins to take shape. Even though the LM's footprint capability is somewhat constrained, at 7000 feet, a very large area is still accessible by implementing the LM-LPD system capability; therefore, at this time (~ 12 seconds after the initiation of the visibility phase) it would appear that the pilot would not redesignate unless a safety-of-flight problem existed. Figures 5 and 6 show similarly the capabilities and constraints at altitudes of 5000 and 3000 feet respectively without a lunar background.

Example Redesignation Case - To provide an example of redesignation the LM crew might encounter, a case was constructed where, through guidance dispersions, the LPD displayed a look angle to a landing point (1340 ft west and 700 ft south of the center of the ellipse) as is shown in figure 7 (LM altitude of 1000 ft). The figure describes an intended landing point in a 350 ft diameter crater. In order to follow the generalized logic of redesignation, either long and/or left of landing point, the Commander selects an area which appears desirable approximately 700 ft left and 490 ft downrange of the crater. He could probably choose a point closer to the crater, but a distance of two crater widths should be allowed to avoid major landing obstacles formed by ejecta. The redesignation would require six lateral and six downrange discrete inputs from the Commander via the attitude hand controller and would result in a vehicle roll response of $\sim 22^\circ$.

Figure 8 displays the vehicle progress and the resulting field of view at a LM altitude of approximately 500 ft. The resulting approach is into a relatively clear landing area with a terminal yaw angle of 27° (as referenced to the original heading).

The redesignation maneuver has cost 39 fps ΔV leaving the remaining 51 fps ΔV redesignation capability for trimming to the final touchdown point. Although a 350 ft diameter crater was used for this example, the same procedure can be used satisfactorily for the avoidance of much larger craters.

The end result would be a correspondingly earlier redesignation (using the larger footprint capability of the higher altitude conditions) according to the crater's size.

General Redesignation Procedure - Obviously, many visual cues will be available to the rigorously trained LM Commander to indicate the accuracy of his displayed flight parameters and the safety-of-flight of the approach path (see ref 4). Unless gross redesignations (> 2500 ft) are necessary, the Commander would be well advised to wait until an altitude of some 3000 ft or less (preferably 1000 ft) is reached before initiating such a redesignation so that LPD system error effects (miss-distance) will be minimized.

In all cases lateral redesignation must be subtly made so that over-control does not occur due to the large magnitude of the correction ($\pm 2^\circ$ crossrange) or due to not allowing the long-period dynamics of the aircraft-like banking maneuver to be completed before another lateral redesignation is commanded. It would also be advisable to keep the computed landing point to the right of the desired target as seen on the surface, so that all terminal crossrange redesignations would have to be made to the left; thereby, avoiding S-turns and implicitly improving visible terrain definition.

In the case of a landing point redesignation, there may be an interaction between the guidance computation and the actual terrain slope in the presence of landing radar updates such that the computed landing point will appear to drift uprange or downrange from the desired point depending on the terrain slope. A planned overcorrection technique is required to keep the computed landing point drifting toward the desired landing point. These techniques were developed as a result of simulation experience and are summarized in the following section:

Specific Redesignation Procedural Steps

a. After an initial landing point redesignation has been made, the command pilot should allow some 7-12 seconds to elapse so that any visual cues, such as drift trends, that might be available will have an opportunity to develop and stabilize.

b. If the LOS computed by the PGNCS is stable and coincident with the LOS to the desired target or if the altitude ~500 feet (just prior to hover), no further corrective action need be taken except for possible "trimming-up" of the approach as resolution improves and small deviations become apparent.

c. In cases where there is a noticeable drift of the PGNCS line-of-sight after the initial redesignation the planned overcorrection is defined in the following logic charts where:

A = Drift direction of PGNCS, LOS (uprange or downrange) with respect to the desired landing site.

B = PGNCS, LOS angular deviation from desired landing site.

C = Magnitude and direction of planned overcorrection with respect to the desired landing site.

d. If the LM commander notes that the point on the surface defined by the PGNCS computed LOS, as called out by the LM pilot, has drifted in a direction, A, (using the accompanying logic table) from the desired landing point by an amount, B, then a planned overcorrection procedure should be initiated by redesignating the PGNCS-LOS, C, of the desired target, or 4 discrete inputs, using the attitude hand controller in the LPD (or automatic) mode.

Overcorrection	A Uprange		A Downrange	
	B	C Downrange	B	C Uprange
First	1°	1°	0.5°	1.5°

e. If the PGNCS computed landing point continues to drift in a direction. (A) .and comes to with an amount. (B) .of coinciding with the desired target then additional overcorrections should be made by redesignating. . (C) .of the desired target or. (D) .discrete inputs.

Overcorrection	(A) Uprange			(A) Downrange		
	(B)	Downrange		(B)	Uprange	
		(C)	(D)		(C)	(D)
Second	0.5°	+1.5°	2	1.0°	-2.0°	2
Third	0.5°	+1.5°	2	1.0°	-2.5°	3

f. If the observed angular drift rate between the PGNCS computed LOS and the LOS to the desired target goes to zero, then after an appropriate observation period, the computed landing point should be redesignated to the desired target location, if necessary, and step b carried out.

g. If an observed drifting trend should reverse, then after an appropriate observation period, step d and subsequent steps, if necessary, should be repeated.

REFERENCES

1. Klumpp, Allen R.: A Manually Retargeted Automatic Descent and Landing System for LEM. MIT-I/L Report R-593, March 1966.

2. "Terminal LM Yaw Angle for LM-LPD Lateral Redesignations;" NASA MSC Memorandum EG27-67-50.

3. Montgomery, Jay D. and Walter, Larry M.: Lunar Module Redesignation Footprint Capability During Final Approach. NASA MSC Internal Note EG67-19, June 1967.

4. Stegall, Joseph F.: Aircraft Simulation of Lunar Landing Approach Trajectories. NASA Program Apollo Working Paper No. 1159, February 9, 1965.

5. "Lunar Landing Site Selection Terrain Criteria;" NASA MSC Memorandum to the Chief of G&C Division from D. C. Cheatham, October 26, 1966.

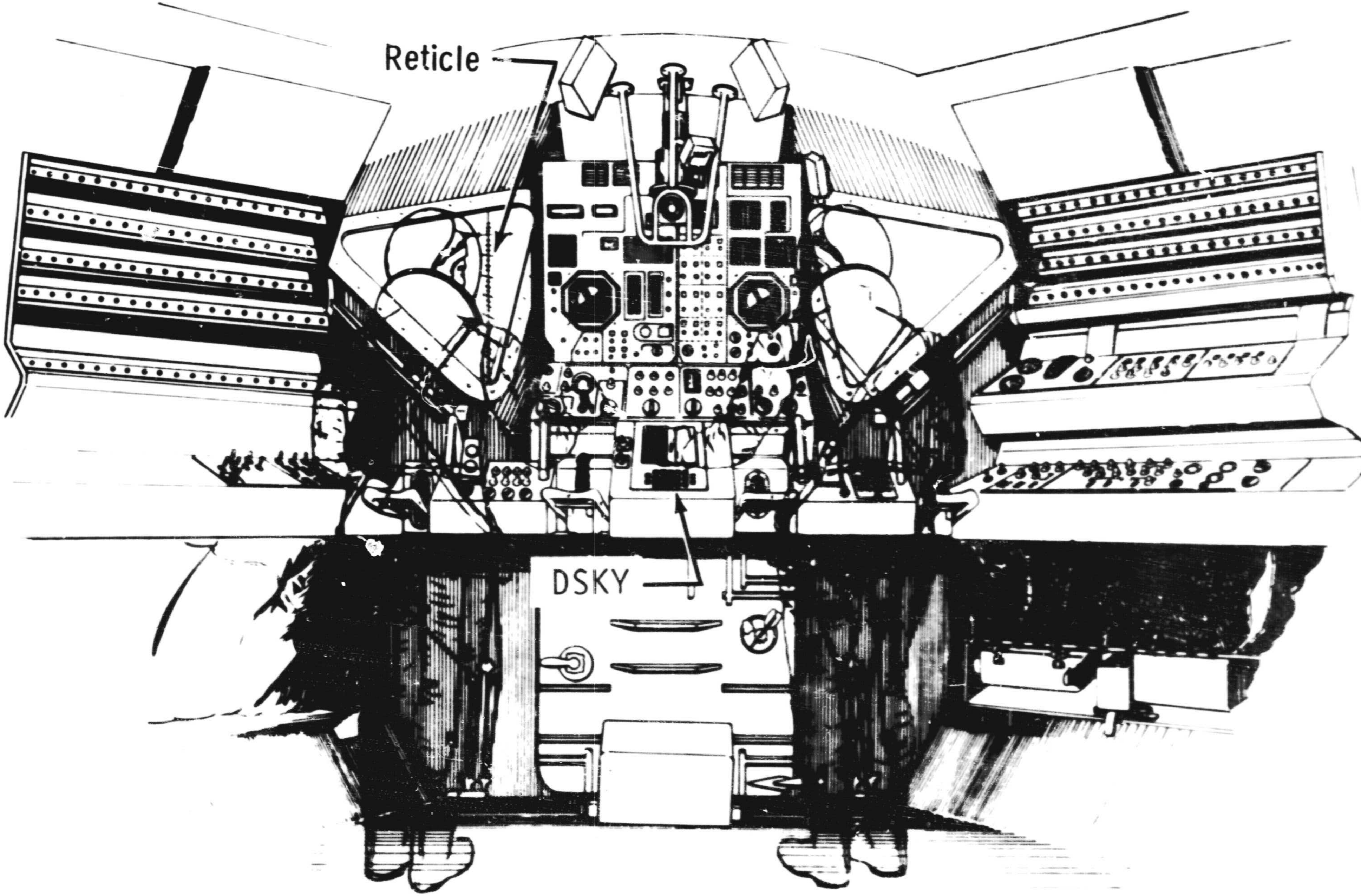

Figure 1. - LM Flight Deck Configuration

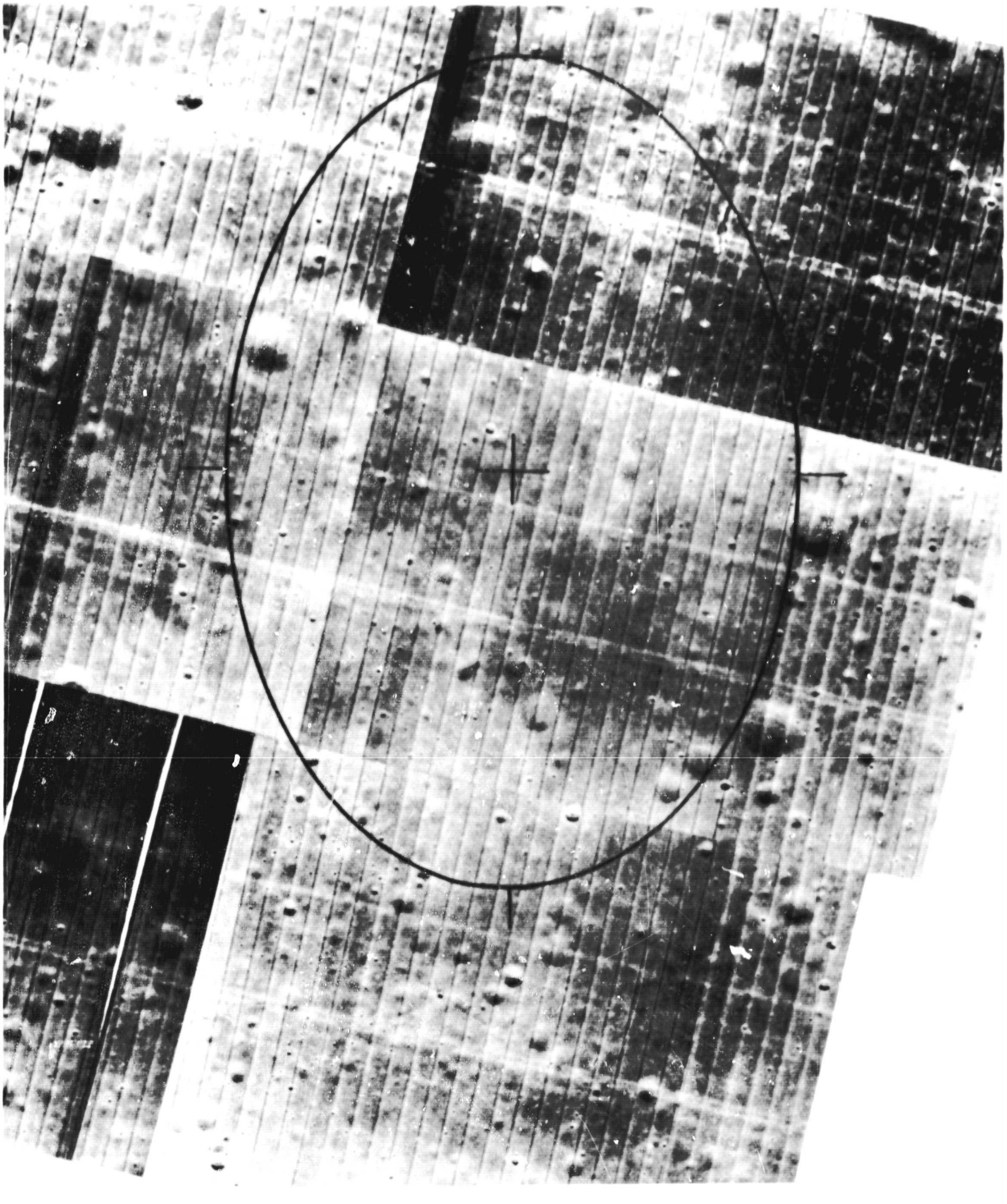

Figure 2. - Primary Lunar Landing Site II P-6-1 with Superimposed LM Fully Automatic Landing, 3σ Dispersion Ellipse

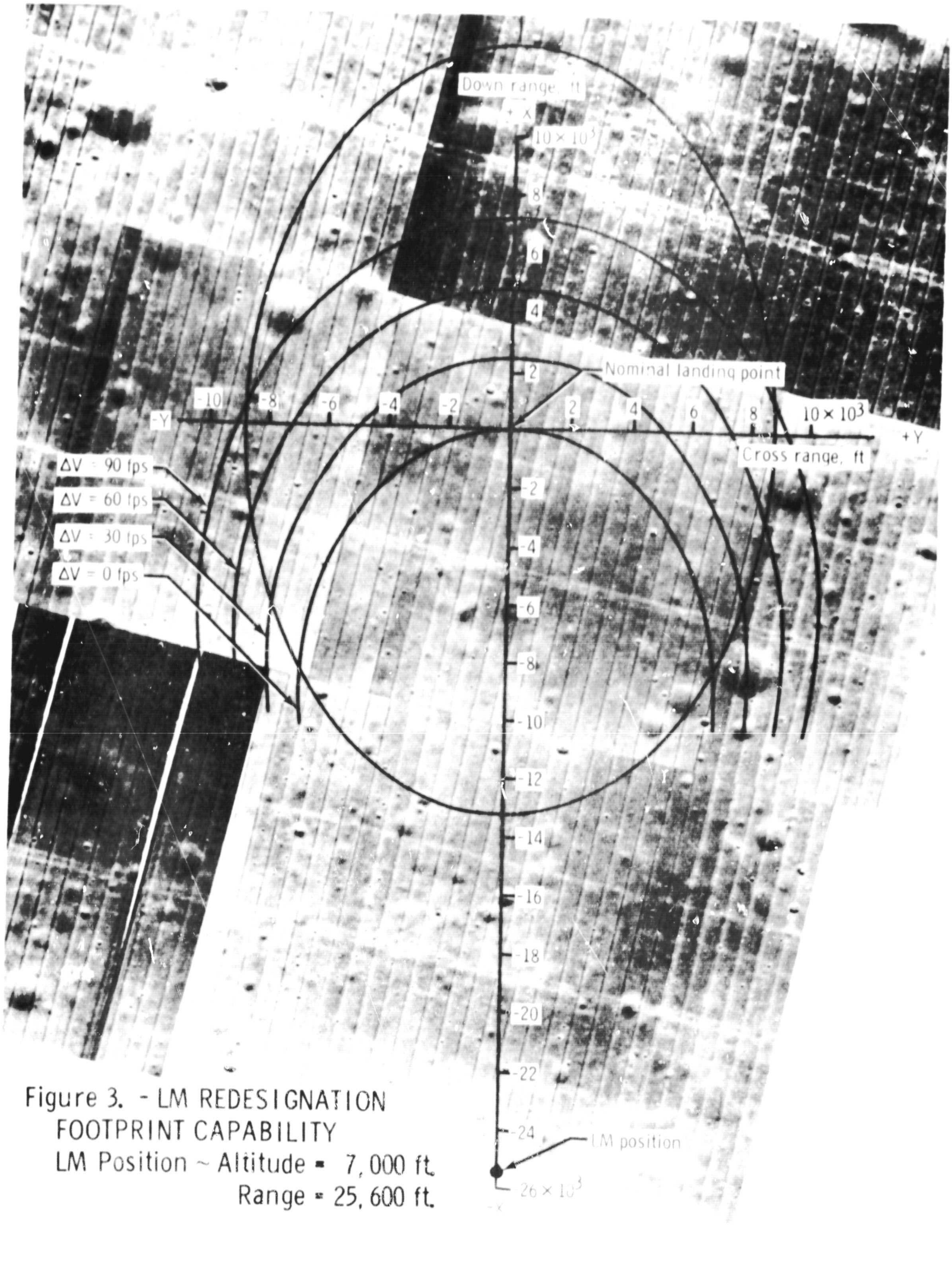

Figure 3. - LM REDESIGNATION FOOTPRINT CAPABILITY

LM Position ~ Altitude = 7,000 ft.

Range = 25,600 ft.

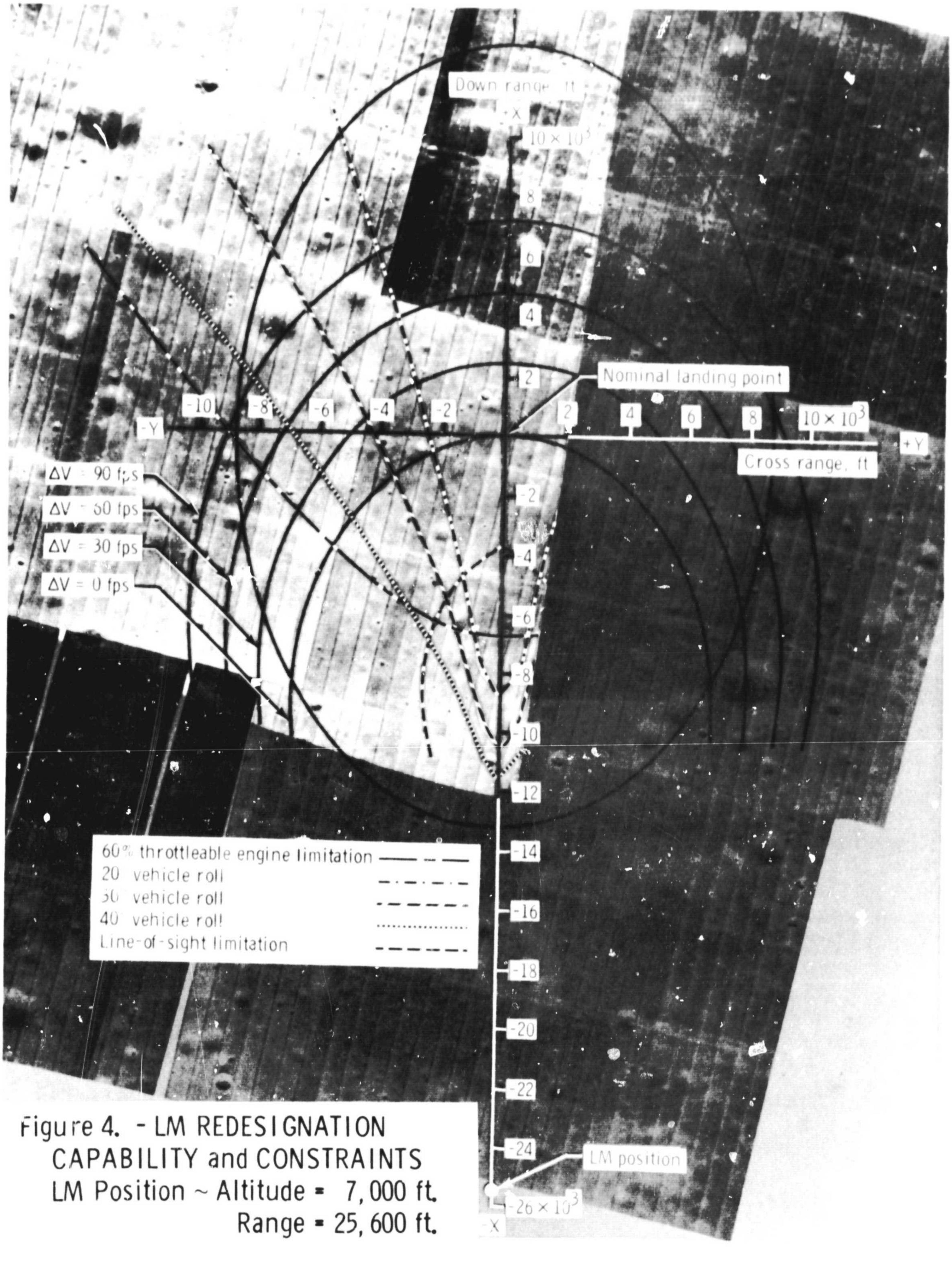

Figure 4. - LM REDESIGNATION CAPABILITY and CONSTRAINTS
LM Position ~ Altitude = 7,000 ft.
Range = 25,600 ft.

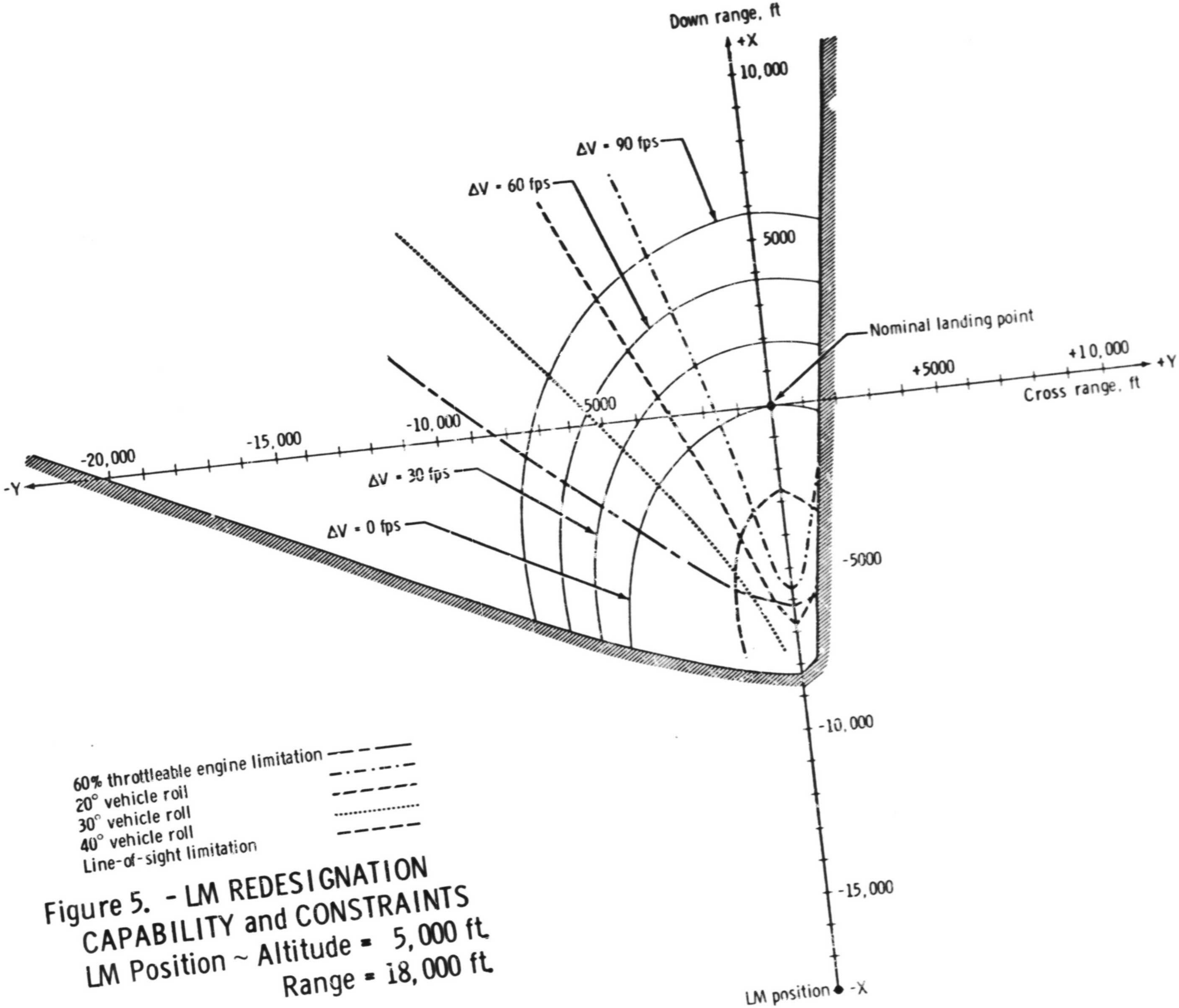

Figure 5. - LM REDESIGNATION CAPABILITY and CONSTRAINTS
LM Position ~ Altitude = 5,000 ft
Range = 18,000 ft

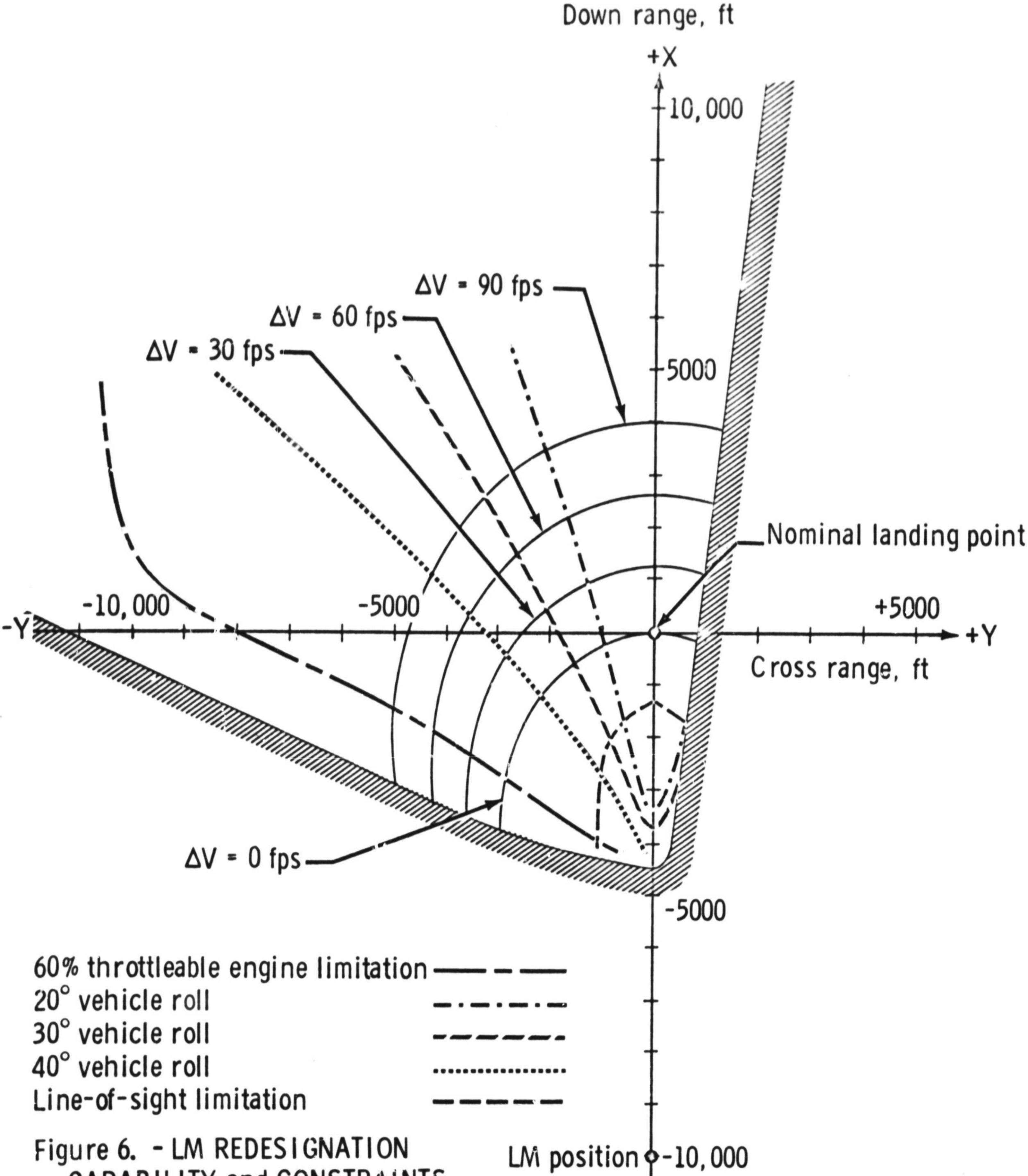

Figure 6. - LM REDESIGNATION CAPABILITY and CONSTRAINTS
LM Position ~ Altitude = 3,000 ft.
Range = 10,200 ft.

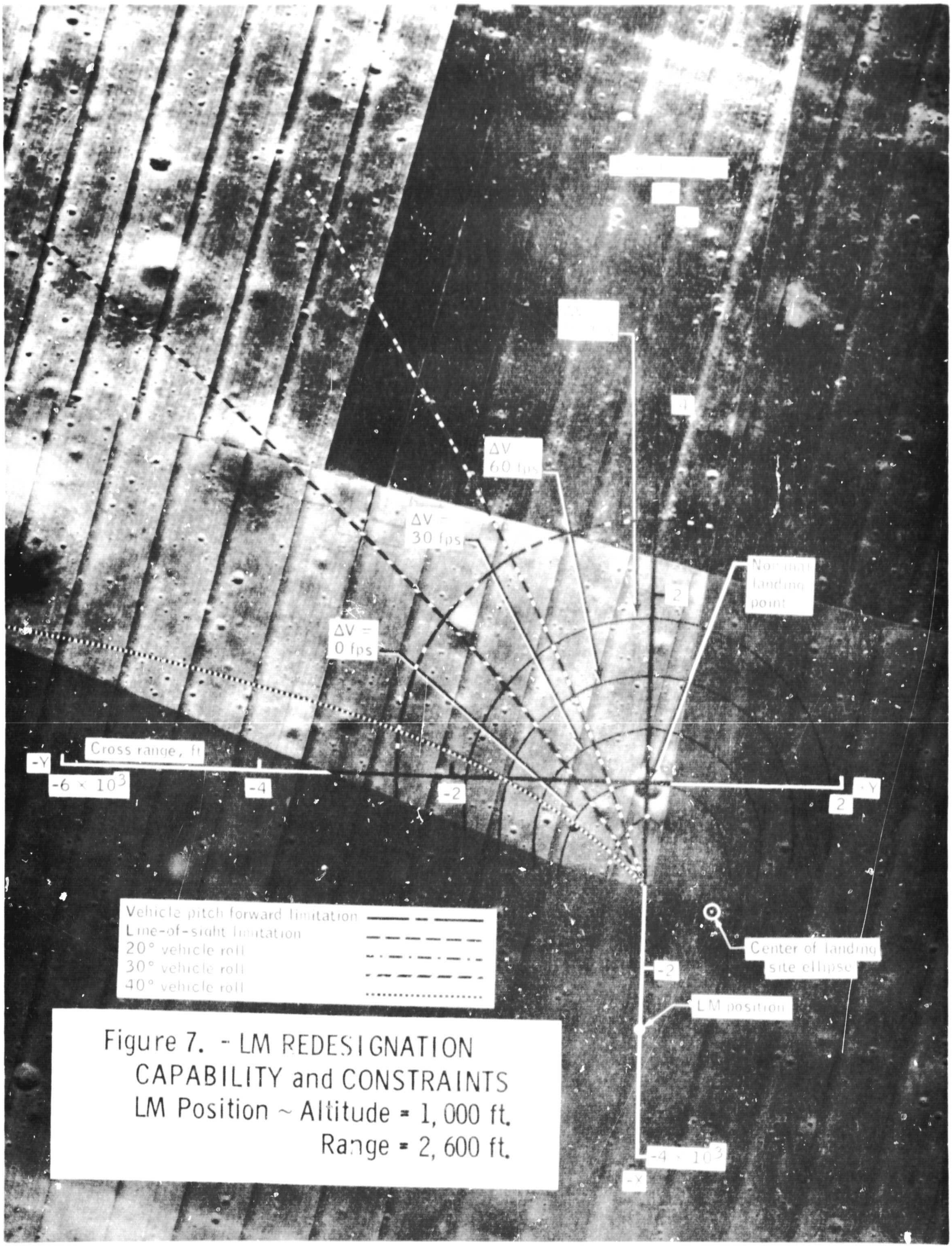

Figure 7. - LM REDESIGNATION CAPABILITY and CONSTRAINTS
LM Position ~ Altitude = 1,000 ft.
Range = 2,600 ft.

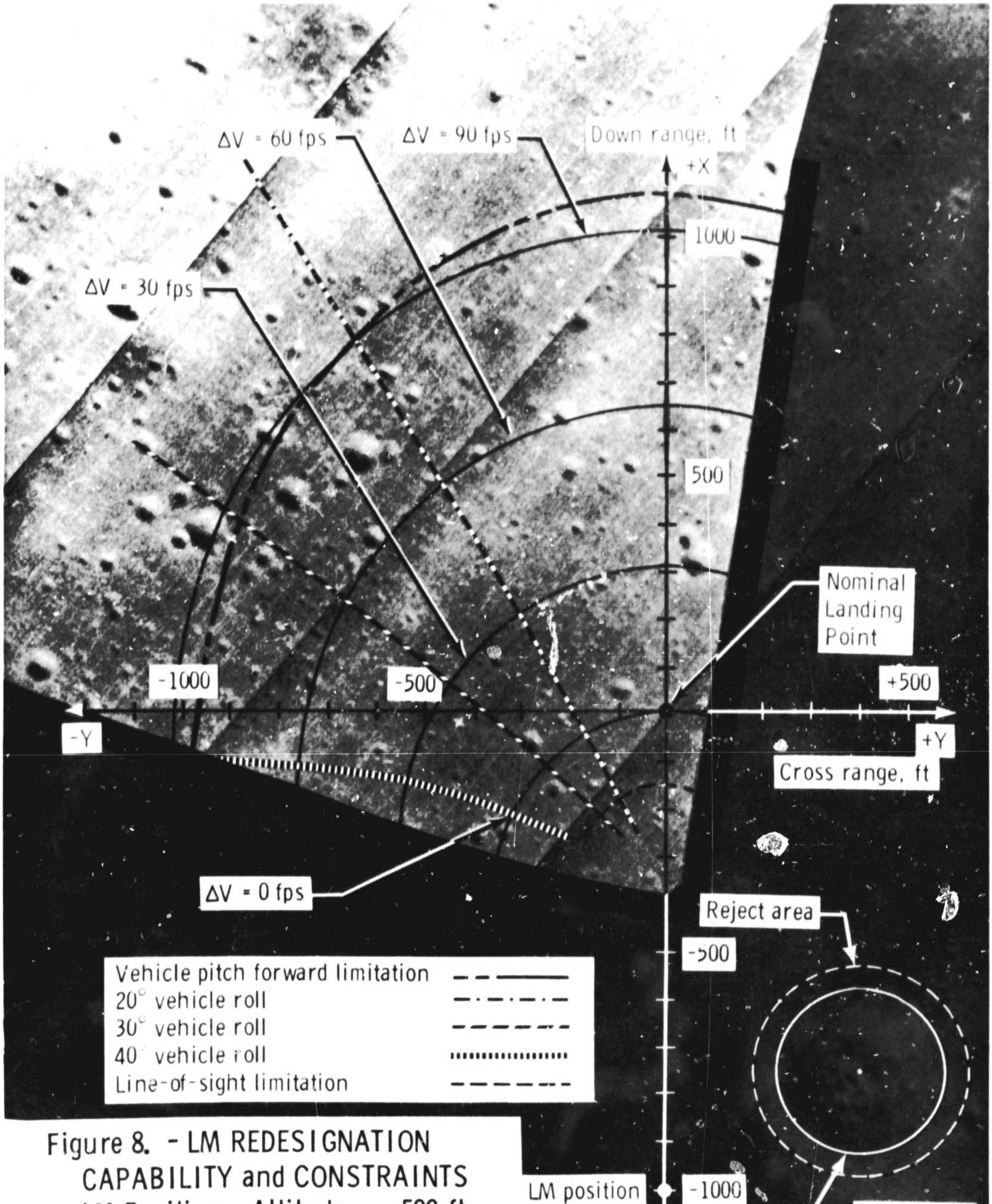

Figure 8. - LM REDESIGNATION CAPABILITY and CONSTRAINTS
LM Position ~ Altitude = 500 ft.
Range = 1,000 ft.